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Subject: An Estimate of the Effect on Greenhouse Gases by Using Recycled Plastic as a Substitute for Treated Wood Railroad Crossties

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Introduction

Background

Recycled-plastic lumber has been under development and in use in the United States at least since 1988, and considerable progress has been made in understanding and controlling its properties, and utilizing it in many traditional chemically treated wood applications. This progress has been helped significantly through the efforts of industry, government, and academia to develop ASTM test methods and standards for these materials. The fairly recent creation of structural types of plastic lumber (that is, with a higher elastic modulus [stiffness] compared to standard plastic lumber materials) have made possible the substitution of recycled-plastic lumber in many structural applications where wood is traditionally used. Examples include railroad (RR) crossties and substructures for decks, docks, and bridges. The substitution of recycled-plastic lumber for chemically treated wood in these applications has heretofore been made almost entirely on the basis of life-cycle costs. However, this study explores the possibility that compelling environmental issues could provide an even greater incentive for this material substitution.

An average of 10 to15 million wooden RR crossties are replaced in the United States every year. Each standard tie is roughly 17.8 x 22.9 x 259 cm (7 x 9 x 102 in.) and weighs approximately 90.7 kg (200 lb). To understand the real magnitude of the number of ties replaced each year, one may consider that 15 million standard railroad ties placed end-to-end would span a distance of nearly 38,600 kilometers (24,000 miles) -- almost the distance once around the earth. Considering that each tie is pressure-treated with several gallons of creosote (which is applied to provide resistance against biological attack), such a quantity of ties also represents millions of gallons of a hazardous chemical being introduced into the environment. If post-consumer recycled plastics could be used to fabricate a replacement for a chemically treated wood tie, it was envisioned that significant amounts of recycled plastics could be diverted from landfill, thus saving many trees from being cut down. In addition, the environment could be spared exposure to many gallons of chemical treatments. It was also thought that the use of recycled-plastic RR ties as a substitute for wood ties might also have a significant benefit regarding the buildup of greenhouse gases (GHG) and the related problem of global warming potential that now may be underway [1].

Objective

The objective of this effort was to estimate the expected positive effect on reducing greenhouse gases by using recycled plastic RR ties as a substitute for traditional treated wood RR crossties. This effort was supported by an Interagency Agreement, #DW96947934-01-0, dated 25 August 1999, between the U.S. Environmental Protection Agency (USEPA), Region 5, and the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). This Memorandum For Record documents the outcome of this study.

Approach

Greenhouse gas factors and calculation methodologies used in this report are taken from the USEPA report entitled "Greenhouse Gas Emissions From Management of Selected Materials in Municipal Solid Waste" [2]. It should be noted here that the GHG benefits could only be estimated based on the best fit of information currently available; possible deviations are noted herein. When more applicable data are developed, the approach presented here can serve as a guideline to more accurately calculate the GHG emissions. It should also be stated that this approach can be used for the analysis of GHG emissions when substituting plastic lumber in many other possible applications where wood is relatively short-lived, including decking, marine pilings, bridges, and even pallets. However, due caution is warranted insofar as several requirements must be met in order to assure that plastic lumber will last for a long time. Mechanical properties of materials and the related stresses of the application must be carefully considered; the design must take into account thermal expansion and fastening issues; and above all, if the material is to be used outside it must have properties that are not significantly affected by sunlight, moisture and temperature cycling. Plastic-lumber-type materials containing high levels of wood-based materials, for example, have been observed to degrade even more rapidly than chemically preserved wood under certain circumstances.

Plastic Railroad Crossties -- State Of The Art

A team made up of Conrail and Norfolk Southern railroads, Rutgers University, and the U.S. Army ERDC-CERL began in 1996 to develop a plastic composite crosstie specification [3] [4] [5]. The specification was based on Class 1 freight applications, which are considered to be the most demanding. This specification provided valuable guidance as to what the research targets would be in terms of product appearance and performance. The philosophy taken by the research team at that time was to develop a specification for a tie that could withstand the most demanding situation that a tie could be expected to endure -- for example, a tie on a mountain curve with heavy freight passing over the track. An alternative approach might have been to develop multiple specifications for different loading conditions, but that approach was not taken because tracking different grades of plastic-based ties was deemed unfavorable.

The target tie was specified to have the general dimensions (17.8 x 22.9 x 259 cm [7 x 9 x 102 in.]) and appearance of a standard hardwood tie, and it would not absorb water, diesel fuel, mineral oil, or grease. The substitute tie would not be electrically conductive or highly susceptible to degradation from environmental exposures or abrasion. Also it would not increase its 143.5 cm (56.5 in.) gauge by more than 0.318 cm (0.125 in.) under a lateral load of 10,900 kg (24,000 lbf) and a static vertical load of 17,700 kg (39,000 lbf). The target tie would be required to sustain a dynamic vertical load of 63,500 kg (140,000 lbf). Installation of the substitute tie should be easily facilitated with standard materials-handling systems, utilizing standard premium fastening systems.

Non-Class 1 railroad systems would be expected to have different (lower) stress levels associated with their use. For example, a short line railroad might require the same static vertical loads but lower lateral loads and dynamic vertical loads because these ties are generally traversed at lower speeds. In a similar fashion, rapid transit systems would be expected to have much lower vertical loads (static and dynamic) but perhaps similar lateral forces produced by lighter trains traveling at higher speeds.

The base material used in nearly all of the currently marketed plastic RR ties is high-density polyethylene (HDPE). HDPE is moisture- and insect- proof but can slowly degrade by oxidation under the influence of ultraviolet (UV) radiation at a rate of up to 0.076 mm (0.003 in.) per year [6]. The properties of most composite plastic ties should, therefore, not deteriorate rapidly in the field. At least two of the currently available composite tie formulations contain at least 60% HDPE by weight. One manufacturer's composite tie, which contains fiberglass, has been shown to not lose any of its mechanical properties when exposed to cyclic moisture, temperature, and UV radiation at levels equivalent to 15 years of exposure for a wood tie. Another manufacturer's composite tie formulation containing HDPE and polystyrene achieved similar results when subjected to the same tests, and was also found to not lose any strength or stiffness after 11 years of outdoor exposure in New Jersey.

To date, at least six manufacturers have produced recycled-plastic based ties -- not all of which meet the previously noted target properties -- that have been installed in various quantities in active track within the United States. Some of these ties have been subjected to extreme accelerated service testing and have shown no signs of failure of any type. The composition of the different ties varies from glass-fiber-reinforced composites, to polymer-fiber-reinforced composites, to mineral-filled polymer composites, to a hybrid plastic, steel, and concrete composite. It is noteworthy that each of these material combinations will have different properties from one another, just as wood from different species of trees has different properties. Newer material combinations will undoubtedly be developed in future.

Depending on composition and quantity involved, plastic RR ties can cost any where from 1.5 to 3 times the amount for treated wood ties. In order to offset these higher initial costs relative to wood, the durability (that is, increased service life) of plastic composite ties must be factored in. If these ties are not able to provide significant increases in durability over traditional materials, their market will be quite limited. Performance durability is also an important issue relative to the greenhouse gas benefits, as will be shown.

Based on the experience of the authors in this area, it is estimated that a recycled plastic composite railroad tie can be engineered to last at least 60 years in service in most, if not all applications, and 100 years of service is not out of the question in typical service exposures. Based on the above-mentioned UV degradation rate of HDPE, for example, a tie based on this material can be expected to lose less than 0.8 cm (less than one-third of an inch) of its 17.8 cm (7 in.) vertical thickness in 100 years. This represents less than a 5% loss in total cross-sectional area, with a corresponding loss in properties expected. Two plastic railroad tie manufacturers currently warrant their ties for 50 years and have laboratory test data showing essentially no degradation of properties in 12-15 year exposures. For ease of calculation we will use a 60-year plastic tie life to calculate the GHG benefit of utilizing recycled plastic ties.

Wood Railroad Crossties -- State Of The Art

The overwhelming majority (93 %) of the approximately 15 million railroad crossties used per year in the United States are wood [7]. Class 1 railroads use predominantly hardwoods like oak, and short line railroads use mixed woods, including softwoods. Metropolitan transit systems use mixed woods (sometimes even exotic rainforest hardwoods) and concrete crossties. Wood ties are typically treated with creosote and (much less often) with chromated copper arsenate (CCA).

Wood tie failures occur most often as a result of one of two mechanisms – biological or mechanical. Biological attack causes tie failure most quickly in areas where the tie is subject to a combination of high moisture and high temperature. Mechanical modes of failure typically occur in tie locations where the highest dynamic lateral forces act on the ties. High dynamic lateral loads can, over time, cause the spike holes to elongate, with subsequent gauge widening or can cause abrasion and wear at the interface of the rail plate and the tie. These phenonina are commonly referred to as “spike killing” and “tie plate cutting,” respectively. In severe exposures, these types of failures can occur in as little as 1 year. To mitigate spike killing, wooden plugs or other synthetic materials are typically inserted into the holes, and the ties are then respiked. This process can usually be done twice, leading to a 3-year life for ties in these most severe service conditions (such as on mountain curves, with heavy tonnage loads). To temporarily work around tie plate cutting, the tie can usually be flipped over and reused. However, once the reverse side also becomes worn, the tie must either be moved for use in low speed applications, such as in a yard, or discarded altogether.

On a straight section of track on the high plains of the United States, a wooden tie can last as long as 50 years. The Chicago Transit Authority and the Metropolitan Transit Agency (New York City) replace their wooden ties roughly every 25 years. Norfolk Southern Corporation replaces many of its ties that are in relatively wet locations in the Southeastern United States every 3 to 5 years. It is difficult to determine how many of the 15 million ties purchased every year go into applications with a short useful tie life, but it is reasonable to assume that a high percentage of the ties sold go into the shortest-lived applications simply because they get replaced much more often.

Greenhouse Gas Calculations

Estimates of the effect of using recycled plastic railroad crossties as a substitute for traditional wooden crossties are detailed below, using referenced numbers from the USEPA report, "Greenhouse Gas Emissions From Management of Selected Materials in Municipal Solid Waste" [2]. The calculations are to be considered as only an estimate because, for example, specific information on the role of hardwood lumber is not found in the referenced document.

In the USEPA document, the units that are pertinent to this comparison are the Metric Ton Carbon Equivalent (of gas) per short ton of (solid) material utilized, or MTCE/ton. In the following, the MTCE/ton "cost" of producing and using a recycled-plastic railroad tie is compared with the MTCE/ton "cost" of producing and using a wooden tie.

Plastic lumber, of which railroad ties is a subset, is typically molded or extruded using unwashed, granulated plastic bottles (predominantly HDPE) as a primary feedstock. The methods of plastic recycling for which data are available in the USEPA report are limited to resin recovery processes, which involve additional washing and extrusion/melt filtering steps. The plastic ties that have been under development in the United States to date are made predominantly from HDPE, with lower percentages of other polymers, and, in some instances, glass fibers or other mineral fillers. We will approximate the MTCE/ton cost for producing a recycled plastic railroad tie to be 0.28, as taken from Exhibit 2-2, column G of the referenced USEPA report. This value includes transportation and processing of recycled HDPE for resin recovery. This number is actually somewhat higher than it should be for plastic lumber production because it involves extra energy-intensive steps, but it is the best information currently available.

No value for the MTCE/ton cost of producing a wooden railroad tie is available in the USEPA report, but MTCE/ton information for the production of dimensional lumber was obtained directly from Mr. Henry Ferland of the USEPA [8]. The average combined process energy emissions, transportation energy emissions, and process non-energy emissions for dimensional lumber have a value of 0.02 MTCE/ton of product. For this estimate, the energy-intensive chemical preservative manufacture and tie treatment processes has not been accounted for. Therefore, while this value is an imperfect estimate, it is nonetheless the best information currently available.

An additional factor must be considered for items produced from wood. Wood comes from trees, which sequester carbon that they remove from the atmosphere. The MTCE/ton cost associated with forest carbon sequestration is 0.73, as taken from Exhibit 3-8 and discussed on page 54 of the USEPA report.

Summing up the above factors, the MTCE/ton benefit for producing a plastic crosstie as a replacement for a wooden tie is equal to the MTCE/ton costs associated with making a wooden tie minus the MTCE cost associated with producing a plastic tie, as follows:

$$(0.73 + 0.02) - 0.28 = 0.47 \text{ MTCE/ton}$$

The above calculation is only an estimate, but is considered to be close. This calculation represents the benefit if the plastic tie lasts only as long as a wooden tie. If a plastic tie outlasts a wooden tie, which it will in most cases, the benefit will be greater. For example, if it is assumed that a plastic tie will last 60 years (at least two of the manufacturers guarantee their ties for 50 years), the calculations are done as follows:

> For the replacement of a wooden tie in a situation where it typically lasts 30 years, MTCE/ton credit for a second wooden tie can be claimed upon installation of a plastic tie, or:

$$2 \times (0.73 + 0.02) - 0.28 = 1.22 \text{ MTCE/ton}$$

> For the replacement of a wooden tie in a situation where it typically lasts 15 years, MTCE/ton credit for a second, third, and fourth wooden tie can be claimed upon installation of a plastic tie, or:

$$4 \times (0.73 + 0.02) - 0.28 = 2.72 \text{ MTCE/ton}$$

> For the replacement of a wooden tie in a situation where it typically lasts just 5 years, MTCE/ton credit for a second, third, fourth, fifth, sixth,....and twelfth wooden tie can be claimed upon installation of a plastic tie, or:

$$12 \times (0.73 + 0.02) - 0.28 = 8.72 \text{ MTCE/ton}$$

> For the replacement of a wooden tie in a situation where it typically lasts just 3 years, as in the most demanding service applications, MTCE/ton credit for a second, third, fourth, fifth, sixth,....and twentieth wooden tie can be claimed upon installation of a plastic tie, or:

$$20 \times (0.73 + 0.02) - 0.28 = 14.72 \text{ MTCE/ton}$$

These are impressive numbers, especially in severe exposure applications where wood ties must be replaced often. The benefit of recycling aluminum (the current MTCE/ton leader of recycling) is about 3 MTCE/ton. This analysis does not include the MTCE associated with actual tie replacement. This number would be hard to estimate in a general sense because of site specific variables attributable to rerouting rail traffic over longer routes for tie maintenance and replacement. However, factoring in such a value would increase the MTCE/ton benefit of plastic composite ties even further. As stated above, these numbers are only estimates, but the concept of substituting a long-lasting plastic item for wood to have a very significant effect on greenhouse gases is a durable principle. These results contradict the common perception that recycling plastic bottles back into bottles (closed-loop recycling) is more environmentally advantageous than producing plastic lumber from bottles (open-loop recycling).

Benefits of Plastic Lumber Applications

Recall that the above results are considered applicable to other plastic lumber applications. The argument for a longer-lasting substitute material for treated wood is expressed in the following quote:

> "Did you know? A full two-thirds of all wood decks replaced are less than 10 years old? More than half of these are replaced because they were rotting, infested with insects, or no longer structurally sound. Building with recycled-plastic lumber eliminates these problems. It also eliminates the need to dispose of the chemically-laden waste of pressure-treated lumber when dismantling that rotting deck. And, you don't have to worry about chemicals leaching from your deck as you relax on your recycled-plastic lumber deck. [9]."

To demonstrate GHG benefits in other applications similar to those estimated for using plastic RR ties, the plastic lumber structure must be designed for a long service life and take into account material properties such as strength, stiffness, creep under long-term loading, and differential thermal expansion [10] [11].

A plastic lumber bridge built at Fort Leonard Wood, MO, can be used to demonstrate the GHG benefits of plastic lumber structures [12] [13]. The original 7.9 meter (26 ft) wide by 7.3 meter (24 ft) long bridge was a wooden structure originally rated for light vehicular traffic, but it had been restricted to pedestrian traffic due to the highly deteriorated state of the wood. A replacement plastic lumber bridge structure was designed and constructed in June 1998. Like the original wooden bridge, the replacement plastic lumber bridge was designed for vehicular traffic. According to base engineering personnel, treated wood structures at Fort Leonard Wood have a life expectancy of 15 years with planned biannual maintenance. (Of course, the amount of maintenance and repair work conducted during this biannual schedule would increase over the years as the wood ages and deteriorates.) For the plastic lumber bridge, materials from four different manufacturers were used. Structural-grade plastic lumber was used for the substructure joists, side-railings, and railing slats, and standard-grade plastic lumber was used for the bridge decking and top railing. To date, this plastic lumber bridge looks like new with no evidence of deterioration or failure.

The materials costs for the plastic lumber materials needed to build this bridge were estimated to be about 2.5 times more compared to the cost of materials for the same bridge made from treated wood. However, given the very low maintenance requirements of the plastic lumber compared to wood, a life cycle cost analysis showed that the plastic lumber bridge would pay for itself in approximately 7.5 years.

As with the plastic RR ties, a 60-year service life is very likely and is used here for ease of the GHG calculations that follow. First, assuming the plastic lumber materials last only as long as treated wood, the MTCE for using plastic lumber as a replacement material for treated wood is the same for the bridge as for the plastic RR ties; that is:

$$(0.73 + 0.02) - 0.28 = 0.47 \text{ MTCE/ton}$$

At a 60-year life expectancy for the plastic lumber, but assuming an average 15-year replacement cycle for a treated wood structure, a wooden bridge would have to be replaced three more times to equal the service life of the original plastic lumber bridge. Considering future bridge replacements, a second, third, and fourth MTCE/ton can be credited, as follows:

$$4 \times (0.73 + 0.02) - 0.28 = 2.72 \text{ MTCE/ton}$$

Approximately 6.5 short tons (13,000 lb) of plastic lumber materials were used to construct the Fort Leonard Wood bridge. By using plastic lumber instead of treated wood to build this bridge, the total GHG benefit equals:

$$6.5 \times 2.72 = 17.68 \text{ MTCE}$$

Similar GHG benefits can be demonstrated for almost any plastic lumber structure. Of course, for these benefits to be fully realized, the structure must be designed properly to minimize system failures over the expected design life. The result also assumes the use of a plastic lumber material with no substantial content of rapidly degradable organic materials.

Conclusions

As demonstrated by the calculations developed in this study, the replacement of recycled-plastic lumber for chemically-treated wood can have a very significant positive effect on reducing greenhouse gases. The exact level of the greenhouse-beneficial effect depends on how frequently the traditional wooden item is typically replaced. Given the large number currently replaced each year, the benefit for replacing plastic RR ties for word RR ties would be significant at any reasonable level of market share. Interestingly in this case, the greatest greenhouse gas benefit occurs where the financial benefit of using a long-life material is also greatest. This finding is an encouraging departure from the many cases in which the most environmentally friendly option ends up being the most costly.

Recommendations

The results of this study suggest the following recommendations:

- MTCE factors for chemically treated wood and recycled, unwashed HDPE should be developed and the GHG benefits for plastic RR ties (and other related plastic lumber materials) recalculated in order to refine the existing numbers and improve their utility in other analyses.

- The environmental benefits of using recycled-plastic RR ties (and other recycled-plastic lumber products) as brought out in this study should be well publicized and referenced in technical papers and other documents especially while stressing the benefits of decreasing GHGs and the penalties for increasing GHGs in the environment. Further acceptance of these benefits could lead to Federal, state and local initiatives and policy changes that would be not only environmentally sound but cost-effective as well.
- Industry and government should support increased research and development for all-plastic lumber outdoor structures (e.g., decks, docks, boardwalks, bridges) with the thought that increased substitution of plastic for wood in such structures would have a positive GHG benefit.
- Research, development, and testing efforts concerning recycled-plastic RR ties should continue as these products still need to gain increased acceptance by the railroad engineering community. Plastic ties have the potential to gain a significant piece of the replacement tie market share, but additional demonstrations will be needed to further demonstrate their performance, including economic and environmental benefits.

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